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(54) **Switch mode ignition coil driver and method.**

(57) A switch mode ignition coil driver includes a means (113) for sensing flyback voltage (195) at the primary winding (103) of the ignition coil (102), and providing a flyback sense voltage (118) indicative of the flyback voltage (195). A means (147) senses current (193) in the primary winding (103) of the ignition coil (102) and provides a current sense voltage (149) indicative of the sensed primary winding current (193). Control means (105,119,129,137,151) is coupled to the means (113) for sensing flyback voltage (195) and the means (147) for sensing current for providing an increasing current through the primary winding (103) of the ignition coil (102) when the flyback sense voltage (118) exceeds a predetermined limit and decreasing this current through the primary winding (103) of the ignition coil (102) when the current sense voltage (149) exceeds another predetermined limit. Further, a corresponding method is disclosed.

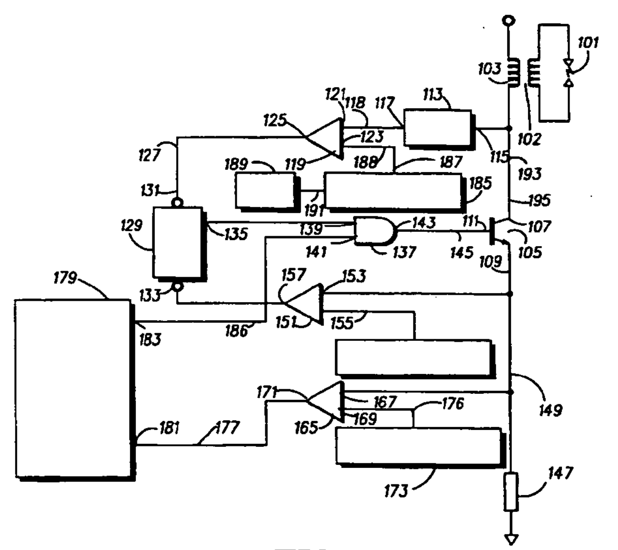

FIG.1

EP 0 566 335 A2

Field of the Invention

This invention is generally directed to coil drivers, and control methods therefor and particularly to coil drivers of ignition systems for internal combustion engines.

Background of the Invention

Ignition systems using linear current regulation schemes for ignition coil drivers are difficult to stabilize and can't be easily designed onto an integrated circuit. This is because they require several discrete components including substantially large capacitors. Designing these ignition coil drivers becomes even more complex and tedious as several analog components, such as the sensing devices as well as power devices are tuned for optimal performance. This tuning is necessary because of variations in gain and frequency response of these analog components. This usually results in long development cycles as extending the components' performance requires some empirical design practice. Previous designs may also rely on active trimming of key components in the production environment adding unnecessary complexity to the manufacturing process. Relying on tuned analog components necessarily compromises optimal energy management. What is needed is an improved design for an ignition coil driver that can be effectively designed onto an integrated circuit.

Summary of the Invention

A switch mode ignition coil driver for driving an ignition coil with a primary is described. Means for sensing flyback sense voltage indicative of the flyback voltage in the primary is provided. Further, a voltage reference means for providing a flyback limit voltage is provided. Then, a means for sensing current in the primary winding and providing a current sense voltage indicative of the sensed primary winding current is provided. Further, a current reference means for providing a current limit voltage is provided. Finally a control means is coupled to the means for sensing flyback voltage and the means for sensing current and provides an increasing current through the primary winding when the flyback sense voltage exceeds the flyback limit voltage and decreasing this current through the primary winding when the current sense voltage exceeds the current limit voltage. Further, a corresponding method is disclosed along with additional circuitry details.

Brief Description of the Drawings

FIG. 1 is a schematic drawing of a switch mode ignition coil driver, in accordance with the invention.

FIG. 2 is a diagram of waveforms used to illustrate various signals in the switch mode ignition coil driver shown in FIG. 1.

Detailed Description of a Preferred Embodiment

In FIG. 1. a switch mode ignition coil driver is illustrated. This includes a spark plug 101 driven by an ignition coil 102 having a primary winding 103. The primary winding 103 of the ignition coil 102 is coupled to and driven by a first output 107 of a transistor switch 105. The transistor switch 105 also has a control input 111 and a second output 109. The primary winding 103 of the ignition coil 102 drives a scaler 113 having an input 115 for measuring flyback voltage at the primary winding 103, and an output 117 providing a scaled flyback sense voltage 118. The output 117 of the scaler 113 then drives a negative input 121 of a flyback voltage comparator 119. A positive input 123 of the flyback voltage comparator 119 is driven by an output 187, providing a flyback limit voltage 188 from a flyback voltage limit reference 185. The flyback voltage limit reference 185 is driven by an output 191 of a battery reference voltage terminal 189. In a preferred embodiment the output 187 of the flyback voltage limit reference 185 is proportional to the output 191 of the battery reference voltage terminal 189. The flyback voltage comparator 119 has an output 125 that is responsive to the difference between the negativ input 121 and the positive input 123 for providing a drive-on signal 127. The output 125 of the flyback voltage comparator 119 drives a set input 131 of a flip-flop 129. The flip-flop 129 also has a reset input 133 and an output 135. The reset input 133 is driven from an output 157 of an over current comparator 151 that provides a drive-off signal 163. The over current comparator 151 has a negative input 153 that is driven by a current sense voltage 149 developed across a resistor 147 that is indicative of the current in the primary winding 103 of the ignition coil 102. The positive input 155 of the over current comparator 151 is driven from an over current limit voltage reference 159 that provides an over current limit reference voltage 161.

An early current comparator 165 has a negative input 167 that is coupled to the resistor 147 for receiving the current sense voltage 149 indicative of the current in the primary winding 103 of the ignition coil 102. The early current comparator 165 also as a positive input 169 that is coupled to an output 175 of an early current limit voltage reference 173 that provides an early current limit reference voltage 176. The early current comparator 165 has an output 171 for providing an early current signal 177 for indicating when the current provided through the primary winding 103 of the ignition coil 102 by the transistor switch 105 exceeds the early current limit reference voltage 176. The early current signal 177 drives an input 181 to an ignition dwell generator 179. This early current signal 177 enables the ignition dwell generator 179 to con-

tinuously adjust a dwell signal 186 provided at a dwell output 183 to minimize the power dissipation in both the transistor switch 105 and the primary winding 103 of the ignition coil 102.

The flip-flop 129 has an output 135 that is responsive to the set input 131 and the reset input 133 for providing an input 139 to a logical AND gate 137. A dwell output 183 of the ignition dwell generator 179 provides the dwell signal 186, with an on-state and an off-state, to an input 141 of the logical AND gate 137. The logical AND gate 137 has an output 143, responsive to the input 139 and the input 141 for providing a command signal 145 for driving the control input 111 of the drive transistor 105.

In FIG. 2 there is an illustration of various waveforms representative of signals present at various locations noted by reference numbers in FIG. 1. All signals are drawn with the same horizontal time scale. The ignition dwell generator 179 provides the dwell signal 186 at its dwell output 183. The logical AND gate 137 provides the command signal 145 at its output 143. The flyback voltage comparator 119 provides the drive-on signal 127 at its output 125. The over current comparator 151 provides the drive-off signal 163 at its output 157. The early current comparator 165 provides the early current signal 177 at its output 171. The primary winding current signal 193 and the primary winding voltage signal 195 are available at the drive transistor's 105 first output 107 and indicate the current flowing through and the voltage across the primary winding 103 of the ignition coil 102 respectively. The primary winding current sense voltage signal 149, developed across resistor 147, varies in an identical manner to the signal 193 shown in FIG. 2

In FIG. 2, at a reference line 215, each signal is reviewed as follows. The dwell signal 186 transits high as indicated by reference number 217. Due to the initial condition of the output 135 of the flip-flop 129, the input 141 and the output 143 of the logical AND gate 137, the command signal 145 also transits high at this reference line 215 as shown by reference number 219. Because the command signal 145 drives the control input 111 of the transistor switch 105, the transistor switch 105 is turned on, and the primary winding voltage signal 195 transits low as shown by reference number 229. This action provides an increasing current through the primary winding 103 of the ignition coil 102. The drive-on signal 127 transits high as shown by reference number 221 because the primary winding voltage signal 195, after being scaled by the scaler 113, is less than the flyback limit voltage 188 provided at the output 187 of the flyback limit voltage reference 185. The drive-off signal 163 and the early current signal 177 remain unchanged as shown by reference numbers 223 and 225 respectively.

As time progresses, the primary winding current signal 193 increases as shown by referenc number 227. This primary winding current signal 193 continues to increase, building the current sense voltage 149 across the resistor 147, until it exceeds the early curr nt limit reference voltage 176 as shown by reference number 233 at reference line 231. When this happens, the early current signal 177 at the output 171 of the early current comparator 165 transits low, as shown by reference number 235.

As time progresses, the primary winding current signal 193 continues to increase, building the current sense voltage 149 across the resistor 147, until it exceeds the over current limit reference voltage 161 as shown by reference number 239 at a reference line 237. When this happens, the drive-off signal 163 at the output 157 of the over current comparator 151 transits low, as shown by reference number 243. This drive-off signal 163 then forces the flip-flop 129 into a reset state providing a low state to the input 139 of the logical AND gate 137. This action results in a transition low of the command signal 145 as shown by reference number 241.

Because the command signal 145 drives the control input 111 of the transistor switch 105, the transistor switch 105 is turned off, as shown at reference number 239, and the primary winding current signal 193 starts to decrease as shown by reference number 246. Also, the primary winding voltage signal 195 starts to build as shown by reference number 245. When the primary winding voltage signal 195 builds, due to flyback action, as indicated by the scaled flyback sense voltage 118, to exceed the flyback limit voltage 188, as shown by reference number 251, the drive-on signal 127 transits low, as shown by reference number 253 at reference line 249. The drive-on signal 127 then forces the flip-flop 129 into a set state, providing a high state to the input 139 of the logical AND gate 137. This action results in a transition high of the command signal 145 as shown by reference number 241.

As time progresses toward reference line 257, because the command signal 145 drives the control input 111 of the transistor switch 105, the transistor switch 105 is turned on, and the primary winding voltage signal 195 transits low as shown by reference number 251. This action again results in the transistor switch 105 providing an increasing current through the primary winding 103 of the ignition coil 102. As a result the primary winding current signal 193, representing the current in the primary winding 103, starts to increase, as shown by reference number 248. Note that the transistor switch 105 has a limited frequency response that provides a slewed slope to the current shown by reference numbers 246 and 248. It is necessary to keep this slew rat b low about 1 amp/millisecond in order not to ignite the spark plug 101. As long as the dwell signal 186 is provided by the ignition dwell generator 179 this cycle will repeat, maintaining the current through the primary winding 103 at a predetermined constant averag level 250 by repetitively

providing an increasing current through the primary winding 103 when the flyback sense voltage 118 exceeds the flyback limit voltage 188 and decreasing this current through the primary winding 103 when the current sense voltage 149 exceeds the over current limit reference voltage 161.

When the dwell signal transits low, as shown by reference number 263 at reference line 261, the maintaining of the current through the primary winding 103 at the predetermined constant average level 250 ceases. This is because the introduction of a low state at the input 141 of the logical AND gate 137 will force the command signal 145 to stay low even when the flyback sense voltage 118 exceeds the flyback limit voltage 188. This will cause the primary winding voltage signal 195 to flyback to a limit set by the drive transistor's 105 internal voltage clamp, in this case about 350 volts as shown by reference number 275.

During a time interval between reference lines 261 and 283 the spark plug 101 is ignited and the primary winding voltage signal 195 will pertubate for a small time as indicated by reference number 277. The primary winding current signal 193 will start to decay forcing the early current signal 177 to a high state as the loss of the current in the primary winding 103, as indicated by the sense voltage 149 across the resistor 147, falls below the early current limit reference voltage 176. As time continues to the reference line 283 the primary winding voltage signal 195 is maintained at a substantially constant level as indicated by reference number 279 until the primary winding is depleted of all current. When this happens the primary winding voltage signal 195 falls as shown by refernce number 281.

This embodiment offers advantages over linear ignition coil driver designs because of the simplicity of the control components. Additionally the tuning process of the linear ignition coil driver design, because of variations in gain and frequency response of the analog components, is eliminated.

Claims

1. A switch mode ignition coil driver for driving an ignition coil (102) having a primary winding (103) comprising:

   means (113) for sensing flyback voltage at the primary winding (103) of said ignition coil (102) and providing a flyback sense voltage (118) indicative of the flyback voltage (195);

   voltage reference means (185) for providing a flyback limit voltage (188);

   means (147) for sensing current in the primary winding (103) of said ignition coil (102) and providing a current sense voltage (149) indicative of the sensed primary winding current (193);

   current ref rence means (159) for providing a current limit voltage (161); and

   control means (105, 119, 129, 137, 151) coupled to said means for sensing flyback voltage (113) and said means for sensing current (147) for providing an increasing current through the primary winding (103) of said ignition coil (102) when the flyback sense voltage (118) exceeds the flyback limit voltage (188) and decreasing this current through the primary winding (103) of said ignition coil (102) when the current sense voltage (149) exceeds the current limit voltage (161).

2. A driver in accordance with claim 1 further comprising means (179) for providing a dwell signal (186), coupled to said control means (105, 119, 129, 137, 151), said dwell signal (186) having an on-state and an off-state, and wherein the current provided by said control means (105, 119, 129, 137, 151) is not provided through the primary winding (103) of said ignition coil (102) when said dwell signal (186) is in the off-state.

3. A driver in accordance with claim 1 further comprising:

   means (179) for providing a dwell signal (186) coupled to said control means (105, 119, 129, 137, 151), said dwell signal (186) having an on-state and an off-state and wherein the current provided by said control means (105, 119, 129, 137, 151) is repetitively increased and decreased to the primary winding (103) of said ignition coil (102) when said dwell signal (186) is in the on-state and no current is provided by said control means (105, 119, 129, 137, 151) to the primary winding (103) of said ignition coil (102) when said dwell signal (186) is in the off-state.

4. A driver in accordance with claim 1 wherein said control means (105, 119, 129, 137, 151) maintains the current through the primary winding (103) of said ignition coil (102) at a predetermined constant average level by repetitively providing an increasing current through the primary winding (103) of said ignition coil (102) when the flyback sense voltage (118) exceeds the flyback limit voltage (188) and decreasing this current through the primary winding (103) of said ignition coil (102) when the current sense voltage (149) exceeds the current limit voltage (161).

5. A driver in accordance with claim 4 further comprising means (179) for providing a dwell signal (186) coupled to said control means (105, 119, 129, 137, 151), said dwell signal (186) having an on-state and an off-state and wherein the current provided by said control means (105, 119, 129, 137, 151) is repetitively increased and decreased

to the primary winding (103) of said ignition coil (102) when said dwell signal (186) is in the on-state and no current is provided by said control means (105, 119, 129, 137, 151) to the primary winding (103) of said ignition coil (102) when said dwell signal (186) is in the off-state.

6. A driver in accordance with claim 1 or 4 wherein said voltage reference means (185) receives an output (191) from a battery reference voltage terminal (189), and wherein the flyback limit voltage (188) provided by said voltage reference means (185) is proportional to said output (191) from said battery reference voltage terminal (189).

7. A switch mode ignition coil driver for driving an ignition coil (102) having a primary winding (103) comprising:

a switch (105) having a control input (111), a first output (107), and a second output (109), wherein the first output (107) is coupled to and provides current through the primary winding (103) of said ignition coil (102);

a voltage scaler (113) with an input (115) and an output (117), wherein the input (115) is coupled to the first output (107) of said switch (105) for measuring flyback voltage (195) of the primary winding (103) of said ignition coil (102) and providing a scaled flyback sense voltage (118) indicative of the flyback voltage (195) to the output (117) of said voltage scaler (113);

a flyback voltage limit reference (185) for providing a flyback limit voltage (188);

a flyback voltage comparator (119) having a positive input (123), a negative input (121), and an output (125), wherein the positive input (123) is coupled to the flyback voltage limit reference (185) for receiving the flyback limit voltage (188) and the negative input (121) is coupled to the output (117) of said voltage scaler (113) for receiving the scaled flyback sense voltage (118), and the output of the flyback voltage comparator (125), responsive to the difference between the positive input (123) and the negative input (121), provides a drive-on signal (127);

a resistor (147) coupled to the second output (109) of said switch (105), and wherein a current sense voltage (149), indicative of the current in the primary winding (102) of said ignition coil (103), is provided at the resistor coupling;

an over current limit voltage reference (159) for providing an over current limit reference voltage (161);

an over current comparator (151) having a positive input (155), a negative input (153), and an output (157), wherein the positiv input (155) is coupled to said over current limit voltage reference (159) for receiving the over current limit reference voltage (161), the n gative input (153) is coupl d to the resistor (147) for receiving the current sense voltage (149) and the output of the over current comparator (157), responsive to the difference between the positive input (155) and the negative input (153), provides a drive-off signal (163); and

a flip-flop means (129) having a set input (131), a reset input (133), and an output (135), wherein the set input (131) is coupled to the output (125) of said flyback voltage comparator (119) for receiving the drive-on signal (127) and the reset input (133) is coupled to the output (157) of the over current comparator (151) for receiving the drive-off signal (163) and wherein the output (135) is responsive to the drive-on signal (127) and the drive-off signal (163); and

a logical AND gate means (137) having a first input (141), a second input (139), and an output (143), wherein the second input (139) is coupled to the output (135) of said flip-flop means (129), and wherein the output (143), responsive to the second input (139) and the first input, (141) provides a command signal (145) coupled to th control input (111) of said switch (105) for providing an increasing current through the primary winding (103) of said ignition coil (102) when th scaled flyback sense voltage (118) exceeds th flyback limit voltage (188) and decreasing this current through the primary winding (103) of said ignition coil (102) when the current sense voltag (149) exceeds the current limit voltage (161).

8. A driver in accordance with claim 7 wherein said logical AND gate means (137) maintains the current through the primary winding (103) of said ignition coil (102) at a predetermined constant average level by repetitively providing an increasing current through the primary winding (103) of said ignition coil (102) when the flyback sens voltage (118) exceeds the flyback limit voltage (188) and decreasing this current through the primary winding (103) of said ignition coil (102) when the current sense voltage (149) exceeds the current limit voltage (161).

9. A driver in accordance with claim 1, 4, or 7 further comprising:

an early current limit voltage reference (173) for providing an early current limit reference voltage (176); and

an early current comparator, (165) coupled to said means for sensing current (147) and coupled to said early current limit voltage reference (173) for receiving the early current limit reference voltage (176), and wherein said early current comparator (165) provides an early current signal (177) when the current sense voltage pro-

vided by said means for sensing current exceeds a current corresponding to th early current limit reference voltage (176).

10. A driver in accordance with claim 9 further comprising:

means for providing a dwell signal coupled to said control means (105, 119, 129, 137, 151), said dwell signal having an on-state and wherein the current provided by said control means (105, 119, 129, 137, 151) is repetitively increased and decreased to the primary winding (103) of said ignition coil (102) when said dwell signal is in the on-state, wherein the early current signal (177) is coupled to said means for providing a dwell signal, and wherein said dwell signal on-state is determined by the early current signal (177).

11. A method of switch mode ignition comprising the steps of:

sensing flyback voltage (113) at the primary winding (103) of said ignition coil (102) and providing a flyback sense voltage (118) indicative of the flyback voltage (195);

providing a flyback limit voltage (188);

sensing current (147) in the primary winding (103) of said ignition coil (102) and providing a current sense voltage (149) indicative of the sensed primary winding current (193);

providing a current limit voltage (161); and

providing an increasing current (119, 129, 137, 105) through the primary winding (103) of said ignition coil (102) when the flyback sense voltage (118) exceeds the flyback limit voltage (188) and decreasing this current (151, 129, 137, 105) through the primary winding (103) of said ignition coil (102) when the current sense voltage (149) exceeds the current limit voltage (161).

12. A method of switch mode ignition in accordance with claim 11 further comprising the step of:

maintaining the current through the primary winding (103) of said ignition coil (102) at a predetermined constant average level by repetitively providing an increasing current through the primary winding (103) of said ignition coil (102) when the flyback sense voltage (118) exceeds the flyback limit voltage (188) and decreasing this current through the primary winding (103) of said ignition coil (102) when the current sense voltage (149) exceeds the current limit voltage (161).

13. A method of switch mode ignition in accordance with claim 11 further comprising the steps of:

providing an early current limit reference voltage 176; and

providing an early current signal (177) when the curr nt provided through the primary winding (103) of said ignition coil (102) by said control m ans (105, 119, 129, 137, 151) exceeds a current corresponding to the early current limit reference voltage (176).

14. A method of switch mode ignition in accordance with claim 11 further comprising the step of:

providing a dwell signal (186) for controlling said step of providing current (119, 129, 137, 105) through the primary winding (103) of said ignition coil (102); and

modifying said dwell signal (186) responsive to the early current signal (177) of said early current comparator (165).

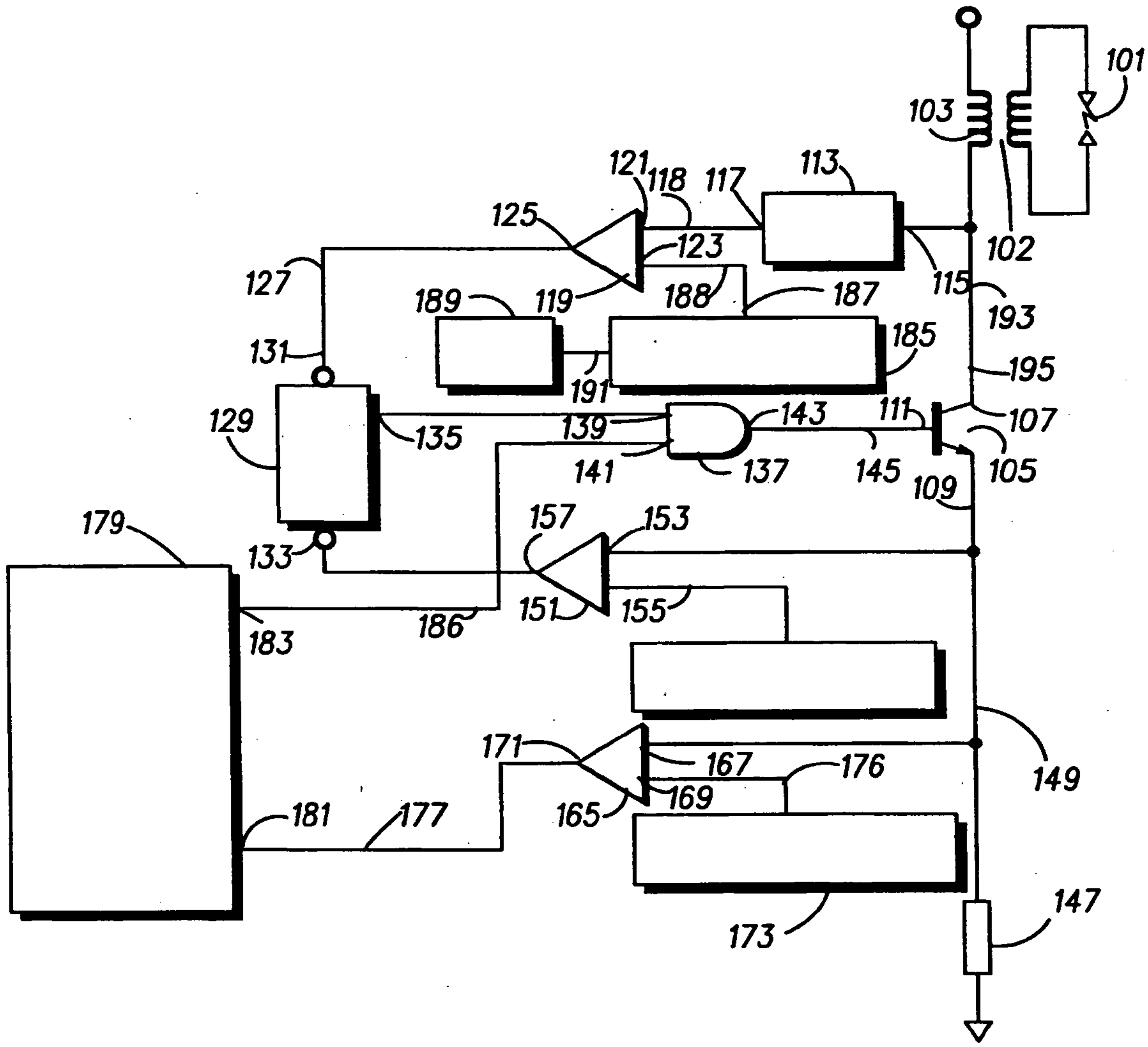
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FIG.1

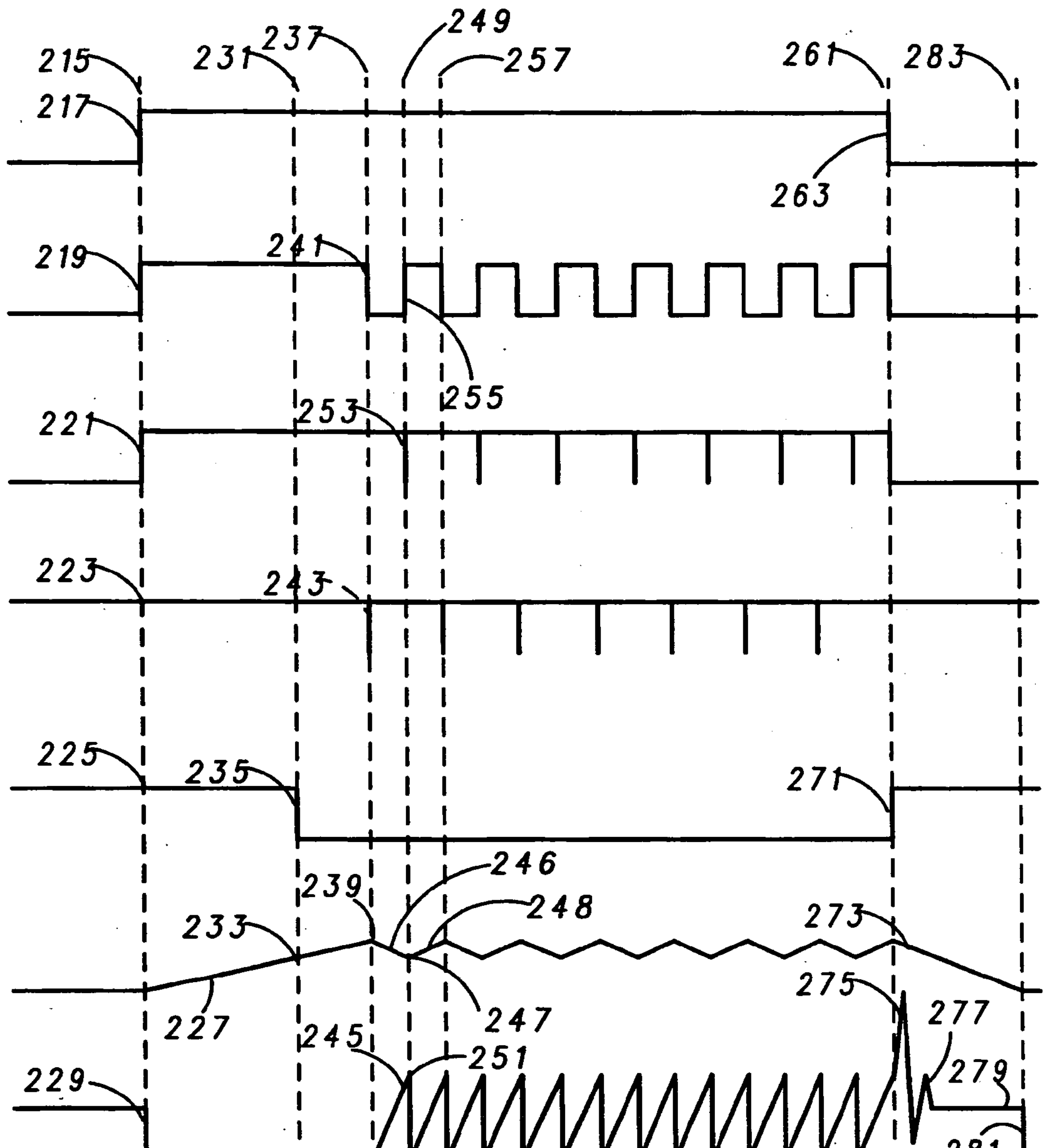
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FIG.2

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(54) Switch mode ignition coil driver and method.

(57) A switch mode ignition coil driver includes a means (113) for sensing flyback voltage (195) at the primary winding (103) of the ignition coil (102), and providing a flyback sense voltage (118) indicative of the flyback voltage (195). A means (147) senses current (193) in the primary winding (103) of the ignition coil (102) and provides a current sense voltage (149) indicative of the sensed primary winding current (193). Control means (105,119,129,137,151) is coupled to the means (113) for sensing flyback voltage (195) and the means (147) for sensing current for providing an increasing current through the primary winding (103) of the ignition coil (102) when the flyback sense voltage (118) exceeds a predetermined limit and decreasing this current through the primary winding (103) of the ignition coil (102) when the current sense voltage (149) exceeds another predetermined limit. Further, a corresponding method is disclosed.

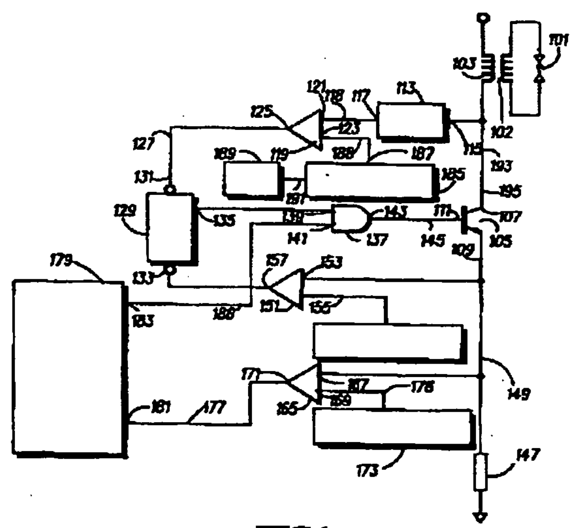

FIG.1

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European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 30 2809

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
X	US-A-4 944 281 (SUQUET)	1-5,11, 12	F02P3/05 F02P3/055 F02P3/045
A	* the whole document *	7,8	

X	GB-A-2 024 941 (ROBERT BOSCH GMBH)	1-5,11, 12	
A	* the whole document *	7,8	

P,A	EP-A-0 526 219 (MOTOROLA INC.)	1-5,7,8, 11,12	
	* column 3, line 9 - column 4, line 8; figure 2 *		

A	EP-A-0 447 975 (MARELLI AUTRONICA S.P.A.)	1-3,7,8, 11	
	* abstract; figures *		

TECHNICAL FIELDS SEARCHED (Int.Cl.5)

F02P

~~The present search report has been drawn up for all claims~~

Place of search	Date of completion of the search	Examiner
THE HAGUE	30 May 1994	MICHELS J.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

European Patent Office

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

- [ ] All claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for all claims.
- [ ] Only part of the claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid.

  namely claims:
- [ ] No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions,

namely:

See sheet -B-

- [ ] All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.
- [ ] Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid.

  namely claims:
- [x] None of the further search fees has been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims.

  namely claims: 1-5,7,8,11,12

European Patent
Office

EP 93 30 2809 -B-

LACK OF UNITY OF INVENTION - A POSTERIORI -

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions,
namely:

1. Claims 1-5,7,8,11,12: Ignition coil driver and method to regulate the primary current at its limit value

2. Claim 6: Primary flyback voltage reference value proportional to supply voltage

3. Claims 9,10,13,14: Ignition coil driver and method to control dwell time in dependence on initial primary current detection as belonging to claims 1 or 11